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ABSTRACT

This memorandum contains CSM weight estimates for the extended lunar missions outlined in the current AAP Ad Hoc study effort. The weights are derived on the basis of the increased expendables necessary for life support, electrical power generation and cabin leakage. Increments to the requirements of the Design Reference Mission DRM IIA were estimated for each mission and added to the baseline CSM weight.

The single launch missions included were: a 28 day lunar orbital mission, an Extended LM with a 3 day surface staytime, and an Augmented LM with an 8 day surface staytime. The dual launch missions combined a 14 day lunar orbital mission with delivery of the unmanned Lunar Payload Module, and included both Extended and Augmented LM missions with surface staytimes of 12 and 14 days respectively.

The CSM weight estimates shown in Figure 3 are highly dependent on detailed mission requirements which remain to be developed. Probably more important are the required changes to the Apollo CSM subsystems for this spectrum of lunar missions. Longer life fuel cells, larger cryogenic storage systems, and increased RCS propellant capacity will require substantial lead times. The development of instrument payloads and associated weights (not included in the CSM weight estimates of Figure 3) should also be considered a critical lead time item.

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SUBJECT: CSM Requirements for Extended Lunar Missions - Case 232

DATE: June 22, 1967

FROM: D. R. Valley

TM-67-1012-7

TECHNICAL MEMORANDUM

INTRODUCTION

This memorandum deals with CSM requirements for extended lunar missions as outlined in the current AAP Ad Hoc study effort. CSM weights associated with each mission type have been derived on the basis of the increased expendables necessary for life support, electrical power generation, and cabin leakage. In addition, estimates for increased RCS requirements and structural weight penalties have been included.

The Design Reference Mission (DRM IIA) (Ref. 1) was used as a base for the Apollo mission requirements. Increments to this were calculated for each of the mission types and added to the baseline Block II CSM weight. The results are shown in Figure 3 which provides a CSM weight for each mission type considered. In addition, the weight losses associated with expendables used prior to lunar orbit insertion and while in lunar orbit are shown. These two weights will be significant factors in determining the Service Module propulsion requirements for the various mission profiles. The increases to the baseline Block II CSM weight are shown in terms of fixed weight and expendable weight increments.

MISSIONS

The following lunar mission types were considered:

Single Launch Missions

I. Lunar orbital - 28 days in orbit

II. Extended LM - 3 day surface staytime

III. Augmented LM - 8 day surface staytime

Dual Launch Missions with an Unmanned Lunar Payload Module for Logistics Delivery

IV. Extended LM - 12 day surface staytime

V. Augmented LM - 14 day surface staytime

Six different CSM configurations are reflected by these missions. Four are associated with the different LM configurations (different staytime capability), one with the 28 day lunar orbital mission, and one associated with delivery of the unmanned payload modules of Missions IV and V. In connection with these unmanned delivery flights, it has been assumed that the CSM's will be used for 14 day lunar orbital missions after assisting in the unmanned landing.

Figure 1 outlines a rough time line for each of the missions and similar data is shown for the design reference mission. Other than the effects of the additional surface staytimes, longer translunar and transearth flight times (110 hrs) are shown to reflect flight profiles different from the basic Apollo mission.

ASSUMPTIONS

The following assumptions were used in determining the CSM weight requirements for each of the missions:

1. Baseline Block II CSM weight (Ref. 3): 23,562 lbs*
2. Metabolic O_2 requirements: 2 lbs/day/man (1/12 lb/man-hr)
3. Cabin leakage rate: 4.8 lbs/day (0.2 lbs/hr)
4. Food requirements: 2 lbs/day/man
5. LiOH requirements: 0.145 lbs/man-hr (Based on DRM IIA LiOH system weight and mission man-hours.)
6. Average electrical power: 2,000 watts
7. Fuel cell reactant consumption rate: 0.9 lb/kw-hr (0.8 lb O_2 and 0.1 lb H_2)
8. Cryogenic storage system weights based on Block II design (Ref. 2a) as follows:

   Hydrogen: 64.9 lbs tank weight for 28 lbs usable H_2

   system weight factor = $\frac{64.9 + 28}{28}$ =

   3.32 lbs/lb usable H_2

*The CSM used for lunar orbital missions is assumed to carry a two man crew and, therefore, the baseline weight was reduced by 500 lbs to 23,062 lbs.

Oxygen: 77.3 lbs tank weight for 320 lbs usable O_2

system weight factor = $\frac{77.3 + 320}{320}$ =

1.25 lbs/lb usable O_2

9. Reserves: DRM IIA indicates about 200 lbs of usable expendables (190 lbs O_2 and 11 lbs H_2) remaining at the time of SM jettison. This quantity was included in the expendable requirements for each mission.

Using these assumptions, the total expendable requirements for each type mission were derived. The results are shown in Figure 2.

SUBSYSTEM CONSIDERATIONS

Electrical Power System

The preliminary definition phase of the Apollo Extension System Study (Ref. 2b) indicated an electrical power generation system consisting of four 1200-hour fuel cells with two of these being redundant for mission reliability reasons. This configuration was assumed for all mission durations exceeding 500 hours. The 3 day Extended LM and 8 day Augmented LM missions were left with the basic Block II electrical power system consisting of three fuel cells. The 8 day Augmented LM mission (441 hours duration) exceeds the 400 hour life rating of the Block II fuel cells, and thus use of three 1200-hour fuel cells can be assumed. The weight and reactant consumption rate of the longer life fuel cells are essentially the same as the Block II version and would have an insignificant effect from a weight analysis standpoint.

Cryogenic Storage System

The oxygen and hydrogen requirements (including DRM IIA reserves) for any of the proposed missions exceeds the storage capability of the Block II CSM system. Either new tank design or additional Block II tanks are required. The Extended LM (3 day staytime) mission requirements could be cared for by one additional set of Block II tanks. The CSM weight developed for this particular mission has been based on this option. The remaining mission types, however, require the addition of more than one set of Block II tanks, and the use of new, larger volume tanks appears preferable. Tank

weights for the LPM delivery and 14 day lunar orbital mission were estimated in accordance with the Block II system weight factors (see Assumptions). Except for the 28 day lunar orbital mission, these tank weights were then used for all remaining CSM configurations, but were off-loaded to meet individual mission requirements. Two sets of these tanks and some additional structural weight penalty were assumed for the 28 day mission.

REACTION CONTROL SYSTEM (RCS)

Data from the Apollo Extension Systems Study (Ref. 2c) indicates a 765 lb increase in RCS propellant required for a 14 day lunar orbital mission. The recommended configuration replaced the present SM RCS tankage with 4 LM RCS oxidizer tanks per quad to provide for a usable propellant capacity of about 2300 lbs. This configuration, with tanks loaded to meet mission requirements, was assumed for the lunar orbital missions. The fixed weight penalty associated with the larger tanks and helium pressurization system amounts to 402 lbs.

STRUCTURAL

Structural weight penalties were estimated on the basis of data taken from the Apollo Extension System Study (Ref. 2d).

REMARKS

The material presented in this memorandum represents a first cut estimate of CSM weights for each of the mission types considered. As detailed mission requirements are developed, especially for electrical power and RCS propellant requirements, the weight picture presented could change considerably. In addition, it should be noted that the CSM orbital mission configuration weight does not include allowances for the orbital instrumentation. For the present, these weights will have to be considered as payloads to be added to the estimates shown. The following types of things should be considered in this category:

1. Scientific instrumentation

2. Weights associated with the data return anticipated (communications and actual weight returned to Earth)

3. Increased recorder requirements

4. Experiment interfaces

5. The effect of thermal profiles for different orbital inclinations (insulation, shielding, and associated attitude control requirements)

6. Allowances for EVA activities

7. Additional navigation and guidance required.

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1012-DRV-hjt

Attachments:
References
Figures 1 - 3

REFERENCES

1. Design Reference Mission IIIA - MSC Report No. PM3/M-171/66, October 30, 1966

2. Final Report - Preliminary Definition Phase Apollo Extension System - NAA, December 13, 1965

   a. SID 65-1526 - Cryogenic Storage System

   b. SID 65-1525 - Power Generation and Distribution Systems

   c. SID 65-1528 - Reaction Control System (CONFIDENTIAL)

   d. SID 65-1532 - Mass Properties (CONFIDENTIAL)

3. Spacecraft and Launch Vehicle Baseline Values - Working Note from G. M. Anderson/Bellcomm to H. E. Gartrell/MSC, W. B. Shapbell/KSC, and R. D. Stewart/MSFC, dated May 2, 1967

	SINGLE LAUNCH MISSIONS				DUAL LAUNCH MISSIONS		
MISSION PHASE	DRM IIA (BASELINE)	LUNAR ORBITAL (28 DAY)	EXT. LM (3 DAY)	AUG. LM (8 DAY)	EXT. LM (12 DAY)	AUG. LM (14 DAY)	LPM (14 DAY ORBITAL) (2 MAN CREW)
PRELAUNCH THRU S-IVB JETTISON	15 HRS (3 MEN)	15 HRS (2 MEN)	15 HRS (3 MEN)	15 HRS (3 MEN)	15 HRS (3 MEN)	15 HRS (3 MEN)	15 HRS (2 MEN)
TRANSLUNAR COAST THRU LUNAR ORBIT INSERTION	64 HRS (3 MEN)	110 HRS (2 MEN)	110 HRS (3 MEN)	110 HRS (3 MEN)	110 HRS (3 MEN)	110 HRS (3 MEN)	110 HRS (2 MEN)
LUNAR ORBIT	49 HRS* (1 MAN)	672 HRS (2 MEN)	86 HRS (1 MAN)	206 HRS (1 MAN)	302 HRS (1 MAN)	350 HRS (1 MAN)	350 HRS (2 MEN)
TRANSEARTH COAST THRU SM JETTISON	88 HRS (3 MEN)	110 HRS (2 MEN)	110 HRS (3 MEN)	110 HRS (3 MEN)	110 HRS (3 MEN)	110 HRS (3 MEN)	110 HRS (2 MEN)
TOTAL MISSION TIME (HRS)	216	907	321	441	537	585	585
TOTAL MAN-HOURS IN CSM	550	1814	791	911	1007	1055	1170

*DRM-IIA ALLOWS FOR 35 HOURS SPENT ON THE LUNAR SURFACE

FIGURE 1 - MISSION TIMELINE

	SINGLE LAUNCH MISSIONS				DUAL LAUNCH MISSIONS		
	DRM IIA (BASELINE)	LUNAR ORBITAL (28 DAY)	EXT. LM (3 DAY)	AUG. LM (8 DAY)	EXT. LM (12 DAY)	AUG. LM (14 DAY)	LPM (14 DAY ORBITAL)
TOTAL TIME (HRS)	216	907	321	441	537	585	585
MAN-HRS IN CSM	550	1814	791	911	1005	1055	1170
O_2 REQUIRED							
METABOLIC (1/12 #/MAN-HR)	46	152	66	76	84	88	98
LEAKAGE (0.2 #/HR)	43	182	64	88	107	117	117
POWER (2 KW-1.6#/HR)	361	1452	514	706	859	936	936
RESERVE (DRM IIA)	190	190	190	190	190	190	190
TOTAL O_2 (LBS)	640	1976	834	1060	1240	1331	1341
H_2 REQUIRED							
POWER (2 KW-0.2 #/HR)	45	182	64	88	107	117	117
RESERVE (DRM IIA)	11	11	11	11	11	11	11
TOTAL H_2 (LBS)	56	193	75	99	118	128	128
FOOD (LBS)	46	152	66	76	84	88	98
LiOH (LBS)	80	264	115	132	147	154	170

FIGURE 2 - EXPENDABLE REQUIREMENTS

MISSION	Δ FIXED WEIGHT (LBS)	ΔCSM EXPENDABLES (LBS)	EXPENDABLES USED PRIOR TO LOI (LBS)	EXPENDABLES USED IN LUNAR ORBIT (LBS)	CSM TOTAL* WEIGHT (LBS)
DRM IIA	-	-	261	200	23,562
28 DAY LUNAR ORBITAL	2100	2678	348	2755	27,900**
3 DAY EXT. LM	188	197	358	274	24,000
8 DAY AUG. LM	548	463	358	524	24,600
12 DAY EXT. LM (DUAL LAUNCH)	821	662	358	723	25,100
14 DAY AUG. LM (DUAL LAUNCH	832	763	358	823	25,200
LPM DELIVERY + 14 DAY ORBITAL	1260	1538	348	1617	25,900**

(ΔFIXED WEIGHT INCLUDES ADDITIONAL FOOD, LiOH, STRUCTURAL PENALTIES, AND INCREASED TANK WEIGHTS FOR CRYOGENIC STORAGE SYSTEM AND RCS PROPELLANT)

*CSM TOTAL WEIGHT LESS USABLE SM PROPELLANT (ROUNDED)
(BASELINE + ΔFIXED WEIGHT + ΔCSM EXPENDABLES)

**BASELINE CSM WEIGHT (23,562) REDUCED BY 500 LBS TO REFLECT THE REDUCED CREW SIZE FOR THE LUNAR ORBITAL MISSIONS

FIGURE 3 - CSM WEIGHT FOR EACH MISSION TYPE